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ABSTRACT

The purpose of this study was to examine the relationship of the time components of the left ventricle. Since one of the ways to investigate cardiac function is to analyze the time intervals between particular events of the cardiac cycle, various time intervals of systole and diastole of the left ventricle were measured from simultaneous recordings of the electrocardiogram, phonocardiogram, cartoid pulse wave, and apex cardiogram. The relationship of the time components was determined by factor analysis. The results showed that the six nonoverlapping intervals, which included the (1) isovolumetric relaxation phase, (2) rapid filling phase, (3) slow filling phase, (4) electromechanical lag, (5) isovolumetric contraction phase, and (6) ejection phase, are relatively independent of each other and of cycle time (with the exception of the slow filling phase). They reflect the factors that account for the variance of all the time components of the left ventricle. These relationships among the intervals appear to be similar for different ages and sex. (RC)

TIME COMPONENTS OF THE LEFT VENTRICLE[1]

B. Don Franks

One of the ways to investigate cardiac function is to analyze the time intervals between particular events of the cardiac cycle. Multichannel recording techniques have provided simultaneous information of electrical, acustic, pressure, and mechanical events for the assessment of cardiac events. Following earlier work by Marcey (1860) and Garrod (1874), Wiggers (1922) divided the cardiac cycle into periods of systole and diastole. Both systolic and diastolic periods were subdivided into smaller phases. Katz and Feil (1923) and Blumberger and Meiners (1959) began the contemporary approach by use of the arterial pulse, electrocardiogram, and phonocardiogram to delineate systolic time phases. The diastolic time phases have been determined by adding the apexcardiogram (e.g., Benchimol, *et al.*, 1961).

Definitions and Measurement

Cycle Time

The complete cycle time (CT), often reported as heart rate (HR) in terms of number of cycles per minute, has been widely used as one component of cardiac output. As such it has been utilized as an indicator of severity of stressors, and as one means of evaluating cardiovascular function at rest and in response to a standard sub-maximal work load. The maximum number of cardiac cycles per minute has also been used as one way to reflect "normal" aging trends, and as one of the measures which can form the basis for exercise prescription. The cycle time response to various levels of sub-maximal work has been used to estimate maximal oxygen uptake in practical field situations.

[1] Introduction to Symposium, Research Section, AAHPER, Atlantic City, March, 1975.

Cycle time (CT) is defined as one complete cardiac cycle. It is measured from an event in one cardiac cycle to the same event in the next cycle. The peak of the QRS complex in the electrocardiogram (ECG) has often been used. The first major component of the second heart sound (S-2) of the phonocardiogram (PCG) is used in this paper since it marks the beginning of diastole[2] (see Figure 1). The use of CT is preferred to HR since it is more

FIGURE 1 about here

precise, although the ease of obtaining HR makes it more feasible in field situations.

Diastole

The resting portion of the cardiac cycle, diastole (DIA) (Wiggers, 1922), is the time from the end of ejection to the beginning of excitation.[3] Left ventricular DIA begins with the closure of the aortic valve and includes isovolumetric relaxation, rapid and slow filling (Wiggers, 1922)(see Figure 2).

FIGURE 2 about here

Isovolumetric relaxation phase. The IRP is the first part of diastole, from the end of ejection to the beginning of filling. It is measured from S-2 (PCG) to O on the apexcardiogram (ACG) (Benchimol, et al., 1961). It has also

[2]Diastole is selected for the beginning of cycle time because of the effects different amounts of filling apparently have on systole.

[3]The mitral valve does not close until after Q, however, only minute filling takes place after Q. Since Q is the beginning of systole, it has arbitrarily been used as the end of diastole.

been called isometric or isovolumic relaxation.

Rapid filling phase. RFP is the time from the beginning of filling to the end of the phase in which the ventricle fills rapidly terminated by the resistance of the ventricle to further stretch (Yang, et al., 1972). It is measured from O to F on the ACG.

Slow filling Phase. SFP (Wiggers, 1922) is the largest portion of diastole, from the end of rapid filling to the onset of stimulation for the next systole. It is measured from F (ACG) to Q (ECG).[4]

Systole

The working portion of the cardiac cycle includes two pre-ejection intervals and the time for ejection (see Figure 3).

FIGURE 3 about here

Electromechanical lag. The EML (Harrison, et al., 1964) is the time from the onset of excitation to the beginning of contraction. It represents the electrical-mechanical delay found in muscles between stimulation and contraction. EML is measured from Q[4] (ECG) to the first major component[5] of the first heart sound[6] (S-1) on the PCG (see Figure 4). EML has also been called

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FIGURE 4 about here

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electropressor latency or asynchronous period (Raab, 1966).

[4] Or the beginning of the QRS complex if there is not a Q.

[5] First major deflection (positive or negative) after peak of R (ECG) is used for S-1

[6] The time for beginning of contraction may not correspond exactly with S-1, but it appears to be the best estimate from atraumatic methods. In addition, acute or chronic changes in the Q to S-1 interval would reflect primarily changes in EML.

Isovolumetric contraction phase. The ICP (Rushmer, 1956) is the time from the beginning of contraction to beginning of ejection. It is measured from S-1 (PCG) to the onset of the steep ascent (C-1) of the carotid pulse wave (CPW) minus the pulse wave transmission time (T PTT) from the heart to neck.[7] ICP is normally calculated by subtracting ejection period from the mechanical systole (S-1 to S-2). It has also been called isometric (Wiggers, 1922) or isovolumic contraction (Wallace, et al., 1962).

Tension period. TP (Frank and Kinlaw, 1962) is the time for both pre-ejection intervals. It is measured from Q (ECG) to C-1 (CPW) minus PTT. It is normally calculated EML + ICP, or total systole (Q to S-2) minus ejection period. TP has also been called excitation-ejection time (Harrison, et al., 1964), isometric tension period (Raab, 1966), or pre-ejection period (Weissler and Garrard, 1971).

Ejection Period. EP (Wiggers, 1922) is the time from beginning to end of ejection, and is normally measured from C-1 to the dicrotic notch (C-3) on the SPW (Weissler, et al., 1961) (see Figure 5). It can be divided into

FIGURE 5 about here

its percussion wave (rapid ejection) and tidal wave (reduced ejection) (Tavel, 1972). It has also been called left ventricular ejection time[8] (Weissler and Garrard, 1971).

[7] PTT is measured from S-2 to C-3 which represent the end of ejection at the heart and neck respectively. The assumption is made that the PTT prior to ejection is the same as PTT after ejection.

[8] In studies dealing with various time components of the left ventricle, it seems somewhat redundant to include LV before ejection time, although it might be helpful if it were the only left ventricular variable used in the study.

Mechanical systole. MS (Weissler, et al., 1965) is the time from beginning of contraction to end of ejection, and is measured from S-1 to S-2 (PCG), or can be calculated ICP + EP.

Total systole. TS (Weissler, et al., 1965) is the time from onset of excitation to the time of ejection. It is measured from Q (ECG) to S-2 (PCG) or can be calculated EML + ICP + EP. TS has also been called electro-mechanical systole (Fardy, 1973).

Summary

Various time intervals of systole and diastole of the left ventricle can electrocardiogram, phonocardiogram, carotid pulse wave, and apexcardiogram be measured from simultaneous recordings of the (See figure 6). The cardiac events marking the beginning and ending of the

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FIGURE 6 about here

INTERVALS ARE:

- end of ejection, S-2 on the PCG:
- onset of filling, O on the ACG;
- end of rapid filling, F on the ACG;
- onset of excitation, Q on the ECG;
- onset of contraction, S-1 on the PCG;
- onset of ejection, C-1 on the CPW minus PTT between heart and neck;
- end of rapid ejection, C-2 on CPW;
- end of ejection of next cycle, S-2.

The points on the indirect recordings do not always correspond precisely to the cardiac events (Luisada and MacCanon, 1972), although they appear to

be valid approximations (Harrison, et al., 1964; Spodick and Kumar, 1968; Weissler, et al., 1961). Some investigators prefer to refer directly to the points on the ECG, PCG, CPW, AND APCG (e.g., it would be Q-S-1 rather than EML; or S-1 to S-2 rather than MS) (e.g., see Fardy, 1973). This reference to the points on the recordings is more accurate, but it is also more cumbersome and is not as easily understood.

Relationship to Cycle Time

The correlations between each of the intervals and cycle time appears to be similar for males and females (Spitler and Franks, 1975) of different ages (Molnar, et al., 1971) (see Table 1). Even in those intervals which tend to vary in length with age and sex, the relationships among the intervals

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TABLE 1 about here

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are quite similar. The correlation to cycle time is very high for DIA and SFP; moderately high for EP, MS, and TS; and low for EML, ICP, RFP, and IRP.

Relationship Among Intervals

The relationship among the intervals is demonstrated by the correlational matrix (see Table 2) and the factors derived from factor analysis (see Table 3).

TABLES 2 and 3 about here

The variance of all the intervals can be accounted for by two major factors and four "specific" factors (Franks, Wiley, and Cureton, 1969; Molnar, et al., 1971; Spitler and Franks, 1975). Factor one reflects primarily the slow filling phase

of diastole, with total diastole, cycle time, and heart rate also having high loadings. Factor two reflects primarily the ejection period, with mechanical and total systole also having high factor loadings. Intervals having high loadings on factor one have moderate loadings on factor two, and intervals with high loadings on factor two have moderate loadings on factor one. For example, DIA has a factor loading of .92 on factor one and .38 on factor two; whereas, EP has a loading of .92 on factor two and .35 on factor one. There are specific factors for IRP, RFP, and EML. TP loads with ICP on the same factor.

Concerning the use of HR (or CT), it is obvious that HR could be substituted directly for factor one. There could be only moderate success in predicting factor two (EP, MS, or TS) from HR alone, and HR would provide almost no information concerning the shorter intervals (RP, RFP, EML, ICP).

Other evidence of the relative independence of the intervals from each other and from CT includes their differential response to postural change (mental and physical stressors) (Franks and Cureton, 1968); and apnea and face immersion in water (Rodgers, et al., 1973).

Summary

The six non-overlapping intervals, IRP, RFP, SFP, EML, ICP, and EP, are relatively independent of each other and of CT. They would reflect the factors that account for the variance of all the time components of the cardiac cycle. These relationships among the intervals appear to be true for different ages and sexes.

References

Benchimol, A., *et al*. The value of the apexcardiogram as a reference tracing in phonocardiography. *American Heart Journal*, 1961, 61, 485.

Blumberger, K., and Meiners, S. Studies of cardiac dynamics. In A. A. Luisada (Ed.), *Cardiology and encyclopedia of the cardiovascular system*, part 4, Vol. II. New York: McGraw Hill, 1959.

Fardy, P.S. Left ventricular time component changes in middle-aged men following a twelve week physical training intervention program. *Journal of Sports Medicine and Physical Fitness*, 1973, 13, 219-225.

Frank, M. N., and Kinlaw, W.B. Indirect measurement of isovolumetric contraction time and tension period in normal subjects. *American Journal of Cardiology*, 1962, 10, 800-806.

Franks, B. D., and Cureton, T. K. Orthogonal factors of cardiac intervals and their response to stress. *Research Quarterly*, 1968, 39, 524-532.

Franks, B. D., Wiley, J. F., and Cureton, T. K. Orthogonal factors and norms for time components of the left ventricle. *Medicine and Science in Sports*, 1969, 1, 171-176.

Garrod, A. H. On some points connected with the circulation of the blood, arrived at from a study of the sphygmograph-trace. *Proceedings Royal Society London*, 1874, 23, 140-151.

Harrison, T. R. *et al*. The relation of age to the duration of contraction, ejection, and relaxation of the normal human heart. *American Heart Journal*, 1964, 67, 189-199.

Katz, L. N., and Feil, H.S. Clinical observations on the dynamics of ventricular systole. *Archives of Internal Medicine*, 1923, 32, 672-692.

Luisada, A. A. and MacCanon, D. M. The phases of the cardiac cycle. American Heart Journal, 1972, 83, 705-711.

Marey, M. J. De l'emploi du sphygmographe dans le diagsostic des affections valvulaires du coeur et des aneurismes des arteres. Academy of Science (Paris), 1860, 51, 813-817.

Molnar, S., Franks, B. D., Jetté, M., and Cureton, T.K. Cardiac time components of boys 7-14 years of age. Medicine and Science in Sports, 1971, 3, 12-17.

Raab, W. Training, physical inactivity, and the cardiac dynamic cycle. Journal of Sports Medicine and Physical Fitness, 1966, 38-47.

Rodgers, K., Lynch, P., and Franks, B. D. Effects of apnea and face immersion in water on the time components of the cardiac cycle. Presented to American College of Sports Medicine, Philadelphia, 1972.

Rushmer, R. F. Anatomy and physiology of ventricular function. Physiological Review, 1956, 36, 400-425.

Spitler, D., and Franks, B. D. Factor analysis of the left ventricular systolic and diastolic time components. Unpublished data, 1975.

Spodick, D. H. and Kumar, S. Atraumatic measurement of the isometric relaxation period of the left ventricle. Aerospace Medicine, 1968, 39, 968-969.

Spodick, D. H. and Kumar, S. Rapid filling period of the left ventricle: measurement by apexcardiography. Aerospace Medicine, 1968, 39, 1351-1353.

Wallace, A. G., et al. Duration of the phases of left ventricular systole. Circulation Research, 1963, 12, 611-619.

Weissler, A. M. and Garrard, C. L. Systolic time intervals in cardiac disease (I). Modern Concepts of Cardiovascular Disease, 1971, 40, 1-4.

Weissler, A. M., _et al_. Relationships between left ventricular ejection time, stroke volume, and heart rate in normal individuals and patients with cardiovascular disease. _American Heart Journal_, 1961, 62, 367-76.

Weissler, A.M., _et al_. The effects of deslanoside on the duration of the phases of ventricular systole in man. _American Journal of Cardiology_, 1965.

Wiggers, C. J. Studies on the consecutive phases of the cardiac cycle, I. the duration of the consecutive phases of the cardiac cycle and the criteria for their precise determination. _American Journal of Physiology_, 1922, 56, 439-459.

Yang, S.S., _et al_. _From cardiac catheterization data to hemodynamic parameters_. Philadelphia: F. A. Davis Co., 1972.

FIGURE 1

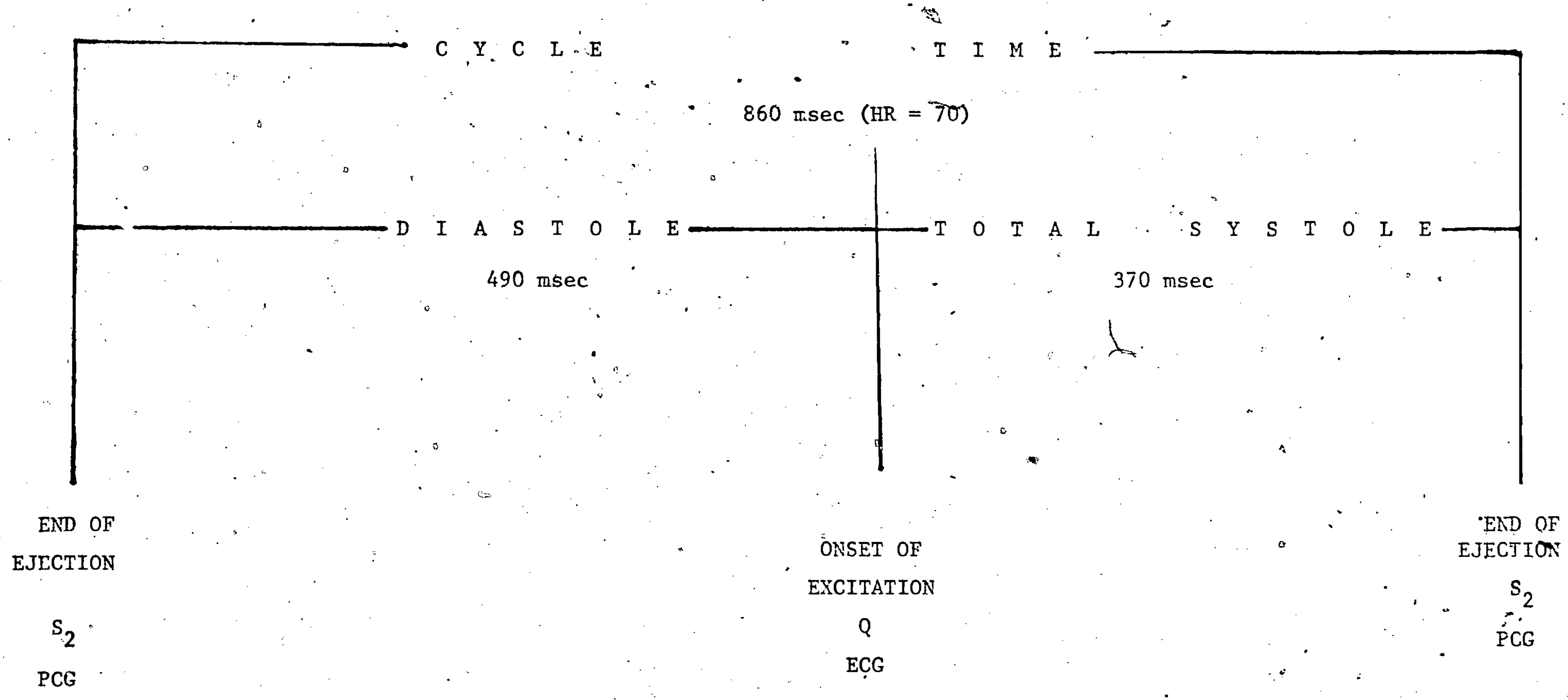

CYCLE TIME
860 msec (HR = 70)
DIASTOLE
490 msec
TOTAL SYSTOLE
370 msec
END OF EJECTION
S_2
PCG
ONSET OF EXCITATION
Q
ECG
END OF EJECTION
S_2
PCG

FIGURE 2

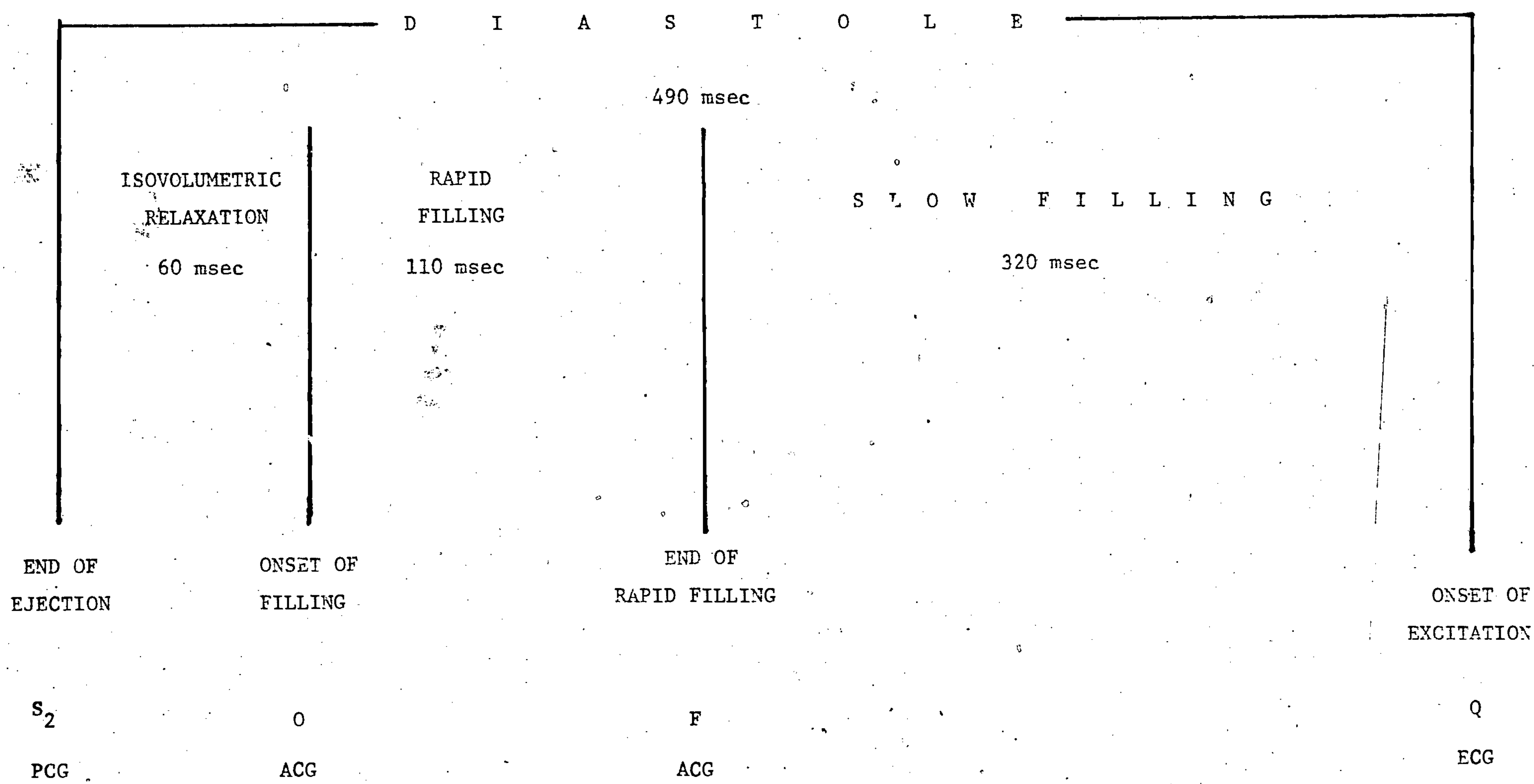

D I A S T O L E
490 msec
ISOVOLUMETRIC RELAXATION
60 msec
RAPID FILLING
110 msec
S L O W F I L L I N G
320 msec
END OF EJECTION
ONSET OF FILLING
END OF RAPID FILLING
ONSET OF EXCITATION
S2
PCG
O
ACG
F
ACG
Q
ECG

FIGURE 3

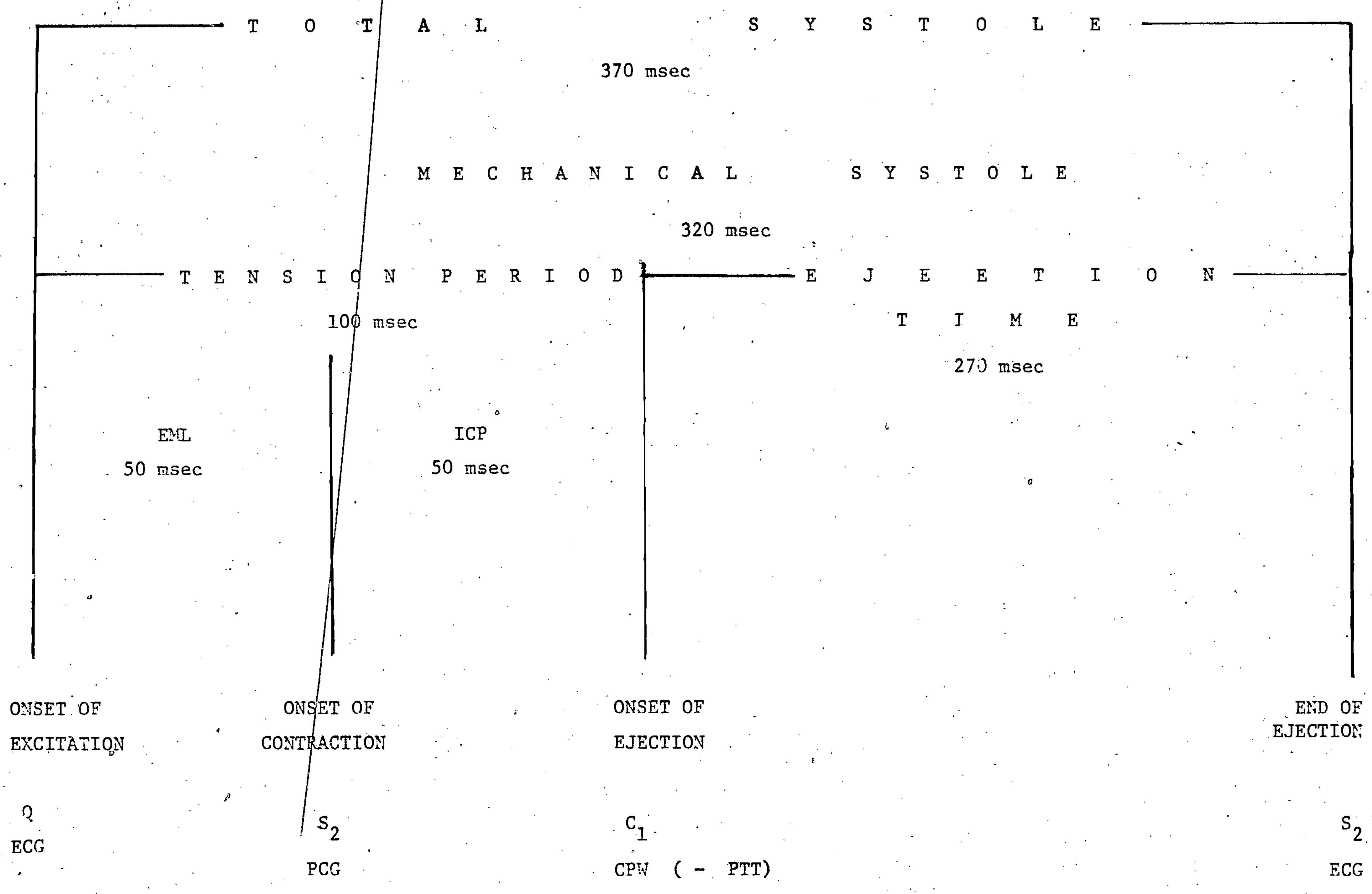

T O T A L S Y S T O L E
370 msec
M E C H A N I C A L S Y S T O L E
320 msec
T E N S I O N P E R I O D
100 msec
E J E C T I O N T I M E
270 msec
EML
50 msec
ICP
50 msec
ONSET OF EXCITATION
ONSET OF CONTRACTION
ONSET OF EJECTION
END OF EJECTION
Q
ECG
S2
PCG
C1
CPW (- PTT)
S2
ECG

FIGURE 4

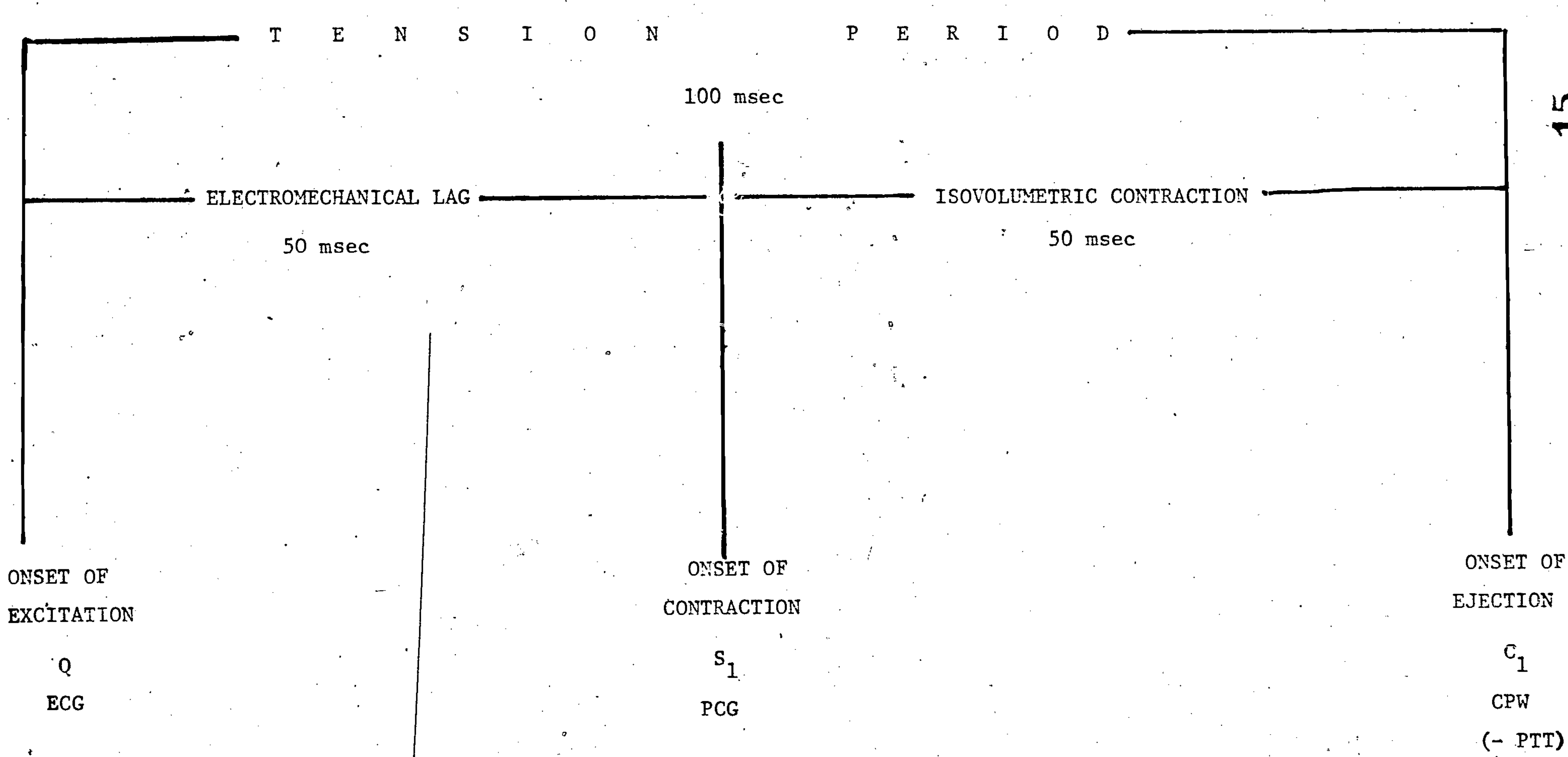
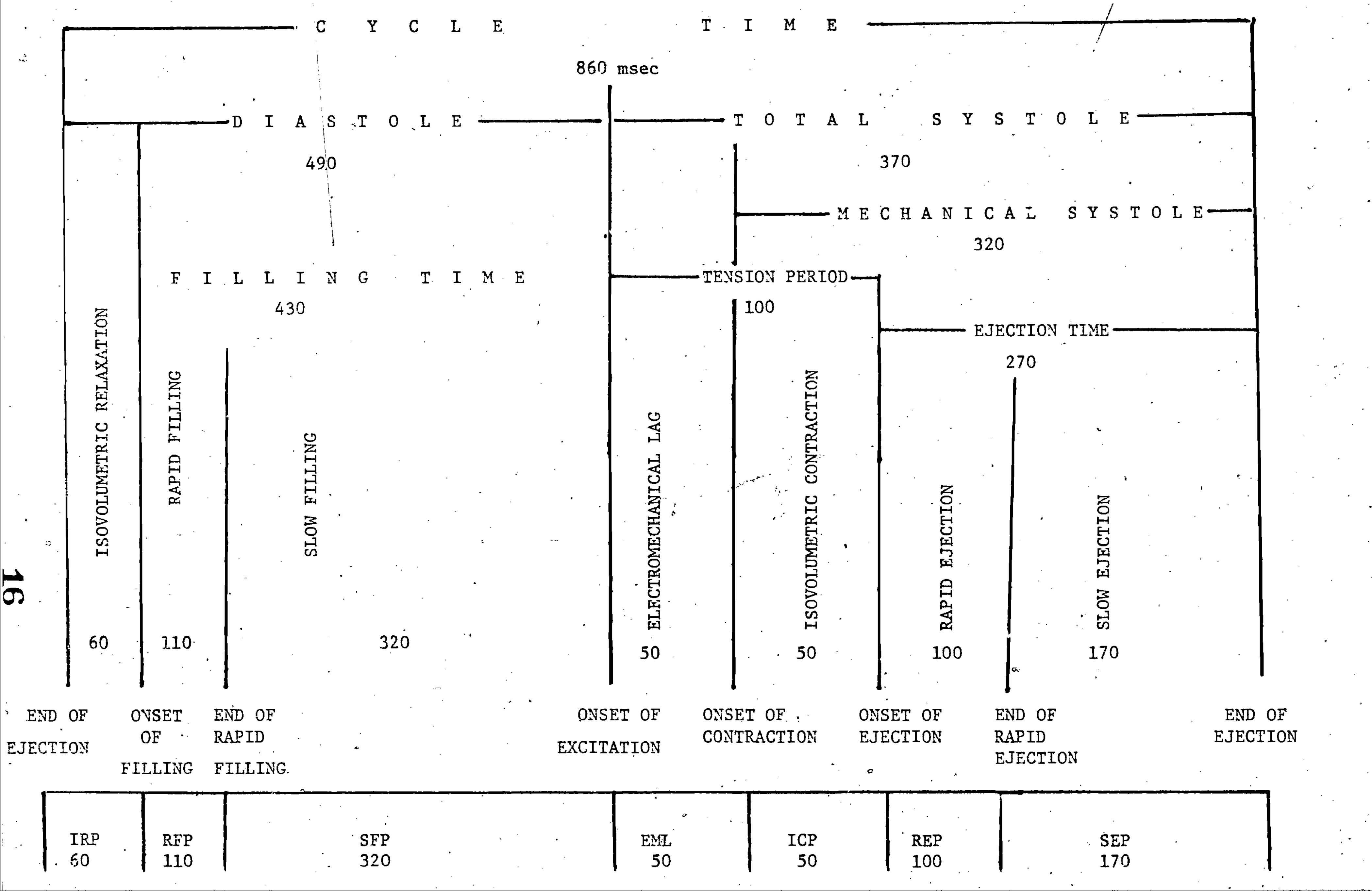

T E N S I O N P E R I O D
100 msec
ELECTROMECHANICAL LAG
50 msec
ISOVOLUMETRIC CONTRACTION
50 msec
ONSET OF EXCITATION
Q
ECG
ONSET OF CONTRACTION
S_1
PCG
ONSET OF EJECTION
C_1
CPW
(- PTT)

FIGURE 5



CYCLE TIME
860 msec
DIASTOLE
490
TOTAL SYSTOLE
370
MECHANICAL SYSTOLE
320
FILLING TIME
430
TENSION PERIOD
100
EJECTION TIME
270
ISOVOLUMETRIC RELAXATION
60
RAPID FILLING
110
SLOW FILLING
320
ELECTROMECHANICAL LAG
50
ISOVOLUMETRIC CONTRACTION
50
RAPID EJECTION
100
SLOW EJECTION
170
END OF EJECTION
ONSET OF FILLING
END OF RAPID FILLING
ONSET OF EXCITATION
ONSET OF CONTRACTION
ONSET OF EJECTION
END OF RAPID EJECTION
END OF EJECTION
IRP 60
RFP 110
SFP 320
EML 50
ICP 50
REP 100
SEP 170

FIGURE 6

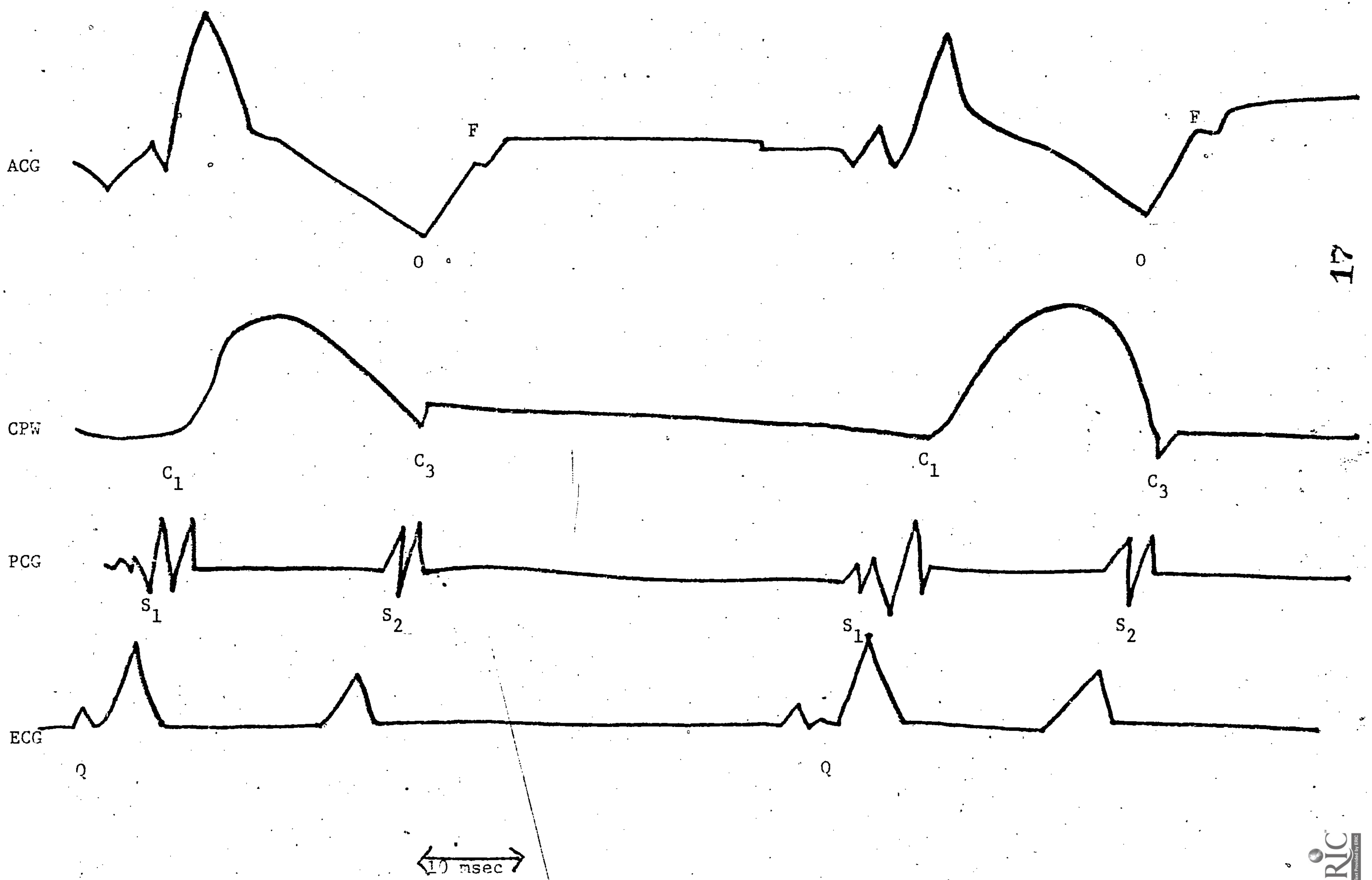


TABLE 1

CORRELATION OF CYCLE TIME WITH LEFT VENTRICULAR INTERVALS

		CYCLE TIME
1.	Diastole	.99
2.	Isovolumetric Relaxation	.26
3.	Rapid Filling	.10
4.	Slow filling	.95
5.	Total systole	.77
6.	Mechanical systole	.76
7.	Electromechanical lag	.23
8.	Isovolumetric contraction	.21
9.	Tension period	.32
10.	Ejection period	.72
11.	Heart rate	-.99

TABLE 2

CORRELATION MATRIX

	1	2	3	4	5	6	7	8	9	10	11	1
1. Heart Rate												
2. Cycle time	-.99											
3. Diastole	-.98	.99										
4. Isovolumetric relaxation	-.26	.26	.26									
5. Rapid filling	-.13	.10	.10	.44								
6. Slow filling	-.91	.95	.96	.05	-.15							
7. Total systole	-.75	.77	.69	.17	.05	.45						
8. Mechanical systole	-.69	.76	.68	.07	-.06	.45	.95					
9. Electromechanical lag	-.24	.23	.19	.30	.37	.10	.39	.09				
10. Isovolumetric contraction	-.07	.21	.18	-.14	-.06	-.04	.34	.38	-.07			
11. Tension period	-.24	.32	.26	.01	.11	.01	.52	.37	.56	.79		
12. Ejection period	-.65	.72	.65	.22	-.03	.64	.86	.95	.14	-.07	.02	

TABLE 3

FACTORS FOR LEFT VENTRICULAR INTERVALS

FACTORS*

1...Diastole**	2...Systole**	3...Isovolumetric contraction
Slow filling	Ejection period	Isovolumetric contraction
Diastole	Mechanical systole	Tension period***
Cycle time	Total systole	
(-) Heart rate		

SPECIFIC "FACTORS"

4. Electromechanical lag	5...Isovolumetric relaxation	6. Rapid filling

*Variables which had highest factor loadings are listed under each factor. Virtually all the variance of the intervals was accounted for by these six factors.

**The variables listed under factor one had moderate loadings under factor 2 (e.g., diastole had a factor loading of .92 for factor one and .38 for factor two). The variables listed under factor two also had moderate loadings under factor one.

***Tension period had a moderate factor loading (.50) under factor 4.